EVALUATION OF CONTROL STRATEGIES TO EFFECTIVELY MEET 70–90% MERCURY REDUCTION ON AN EASTERN BITUMINOUS COAL CYCLONE BOILER WITH SCR

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ABSTRACT

Mercury control evaluations are underway at PSNH Merrimack Station Unit 2. This unit fires medium-sulfur bituminous coal in a cyclone boiler and is configured with an SCR and ESP. It has demonstrated unusually low native mercury capture due to relatively high flue-gas temperatures in the ESP and SCR-generated SO_3 concentrations. Testing is being conducted to evaluate the effectiveness of activated carbon to achieve at least 50% mercury control beyond baseline capture and to demonstrate an interim approach to meet New Hampshire state legislation regarding early mercury reduction goals. DOE/NETL PSNH, ADA-ES, Inc., and other industry partners are funding the project. This paper will present results from tests evaluating the co-benefit of dual injection of sorbents for SO_3 and mercury, and from parametric and initial long-term testing with the most promising sorbents.

INTRODUCTION

Public Service of New Hampshire (PSNH) worked with the New Hampshire (NH) Legislature and the NH Department of Environmental Services (DES) to review the technical feasibility and costs associated with different levels of mercury control at the company's coal-fired power plants. NH House Bill 1673, signed into law by the Governor of New Hampshire, requires by July 1, 2013, an 80% reduction of mercury emissions from PSNH's coal-fired power plants. The law provides incentives to achieve mercury reductions prior to July 1, 2013. This law also prohibits PSNH from participating in a proposed federal mercury cap and trade system to comply with the NH reductions. In addition, PSNH will have to comply with the Clean Air Mercury Rule (CAMR) recently promulgated by the EPA, and meet specific reductions as an initial phase in 2010. Because of early reduction language in the state regulation bill, PSNH is choosing to address issues now that many plants across the country will face over the next few years.

Merrimack Station Unit 2 (MK2) is a very difficult yet important application for mercury reduction technology for a number of reasons. MK2 has a Selective Catalytic Reduction (SCR) system that oxidizes SO_2 into SO_3. The latter species is detrimental to mercury capture with activated carbon injection. Thus, the flue gas stream, which is generated from the combustion of a medium-sulfur (1.2% target) blended coal supply, resembles that of a high-sulfur flue gas stream, in terms of the SO_3 content. In addition, typical flue gas temperatures range from 330 to 350°F, which is in the range that detrimentally impacts activated carbon performance.

Prior to implementing the permanent compliance strategy of installing a wet scrubber in 2013, it is important to gather data and assess whether PSNH can economically achieve the early mercury reductions allowed under NH House Bill 1673 while meeting guiding principles that include (1) integrating environmental quality, public health and safety, and economic vitality; (2) facilitating scientifically and technically sound, cost-effective, and environmentally appropriate solutions; and (3) protecting fuel diversity, and PSNH's ability to generate low-cost, reliable energy necessary to meet customer demand.

MK2 fires a medium-sulfur blend of eastern bituminous and Venezuelan coals into a cyclone boiler and is configured with an SCR and a tubular air preheater (APH) followed by two electrostatic precipitators (ESPs) aligned in series. This allowed an evaluation of the effects medium-sulfur coal flue gas on the mercury removal performance of injected sorbents and the impact of injected sorbents on the performance of the ESP. SO_3 mitigation was also tested in this program, because it provided co-benefits, such as better performance of activated carbon for mercury control and lower cold-end temperatures (CEAs), which improved the unit heat rate. Standard coal usage for MK2 is eastern bituminous. For the duration of these tests, MK2 will fire a test blend of eastern bituminous and Venezuelan coals to study balance-of-plant impacts while lowering baseline mercury inputs into the combustion process.

Activated carbon injection (ACI) is a relatively low capital-cost mercury control option for power plants; however, the economic effectiveness of utilizing the ACI system for power plants that fire medium- to high-sulfur coals can be greatly reduced if high injection concentrations of sorbent are required to effectively lower mercury levels to comply with CAMR and other regulations. Additionally, high sorbent injection rates can increase particulate emissions and can reduce the ability of the plant to utilize/dispose of the fly ash–activated carbon mixtures. The addition of sorbents/reagents to reduce SO_3 also adds to the particulate emission concerns and increases the difficulty of ash utilization/disposal.

Full-scale sorbent injection tests were performed at MK2 following two approaches: the injection of a powdered activated carbon (PAC) sorbent designed to operate in an SO_3 flue gas environment and a co-benefit approach with a dual injection system designed to first limit the SO_3 levels in the flue gas and then remove the mercury via more conventional activated carbon injection.

SO_3-Tolerant PAC Sorbents

There are several sorbent producers developing SO_3-tolerant activated carbon sorbents to maintain efficient mercury removal when SO_3 concentrations are relatively high in the gas stream. NORIT Americas had a sorbent that was available for parametric testing and was promised to be commercially available if the test results supported long-term testing using this approach. NORIT's product was based on the DARCO® Hg-LH brominated PAC and designated as DARCO® E-26. Calgon also had a sorbent that was conceptually designed to be SO_3 tolerant, but Calgon was not ready to support full-scale testing of the product.

Co-Benefit Approach

Another method for mercury removal in an SO_3 flue-gas stream is a dual injection approach. This was especially promising for PSNH MK2 as the plant uses a tubular APH, which limits the ability of the plant to lower flue gas temperatures due to the potential condensation of SO_3 and subsequent corrosion of the downstream ductwork and equipment. In this approach, a sorbent designed to reduce SO_3 levels in the flue gas was injected upstream of the APH. The direct co-benefit of lowering SO_3 levels in the flue gas is the ability of the plant to lower flue gas temperatures by a much as 30°F. This results in a measurable improvement in plant efficiency. With SO_3 levels reduced, the efficiency of PAC to lower mercury emissions is greatly enhanced, through both the lower flue gas temperatures and the lower SO_3 levels in the flue gas.

SO_3 Reduction Sorbents

The two SO_3-reduction sorbents chosen for full-scale testing were magnesium oxide (MgO) and sodium sesquicarbonate (trona). These two sorbents were selected based on performance criteria. Trona was selected because is was the most effective of the carbonate-based sorbents and MgO was selected because previous tests at MK2 showed that it is an effective SO_3 reduction sorbent and is relatively benign for ash disposal.

A critical consideration for PSNH in selecting a sorbent was the ability of the plant to assimilate that sorbent stream into their existing plant coal combustion by-product utilization stream. Even though trona injection was deemed problematic due to the increase in sodium content of the fly ash, it was selected because of its proven ability to reduce SO_3 and, unlike MgO, its minimal impact on ESP performance. With a cyclone boiler, the amount of fly ash produced is less than a pulverized coal-fired boiler; therefore, the levels of sodium in the fly ash would be significantly increased with trona injection.

EXPERIMENTAL

Description of Merrimack Station Unit 2

PSNH's MK2 served as the host site for this test program. During the testing, Unit 2 fired a test blend of eastern bituminous and Venezuelan coals (1.2% sulfur target). The unit is rated at 335 MW. Unit 2 is equipped with one SCR and APH with two ESPs in series downstream of the APH. The APH is a tubular design. Table 1 summarizes the basic design parameters of the unit. Figure 1 shows the Unit 2 configuration along with the injection and sampling locations. Testing was conducted across the full unit.

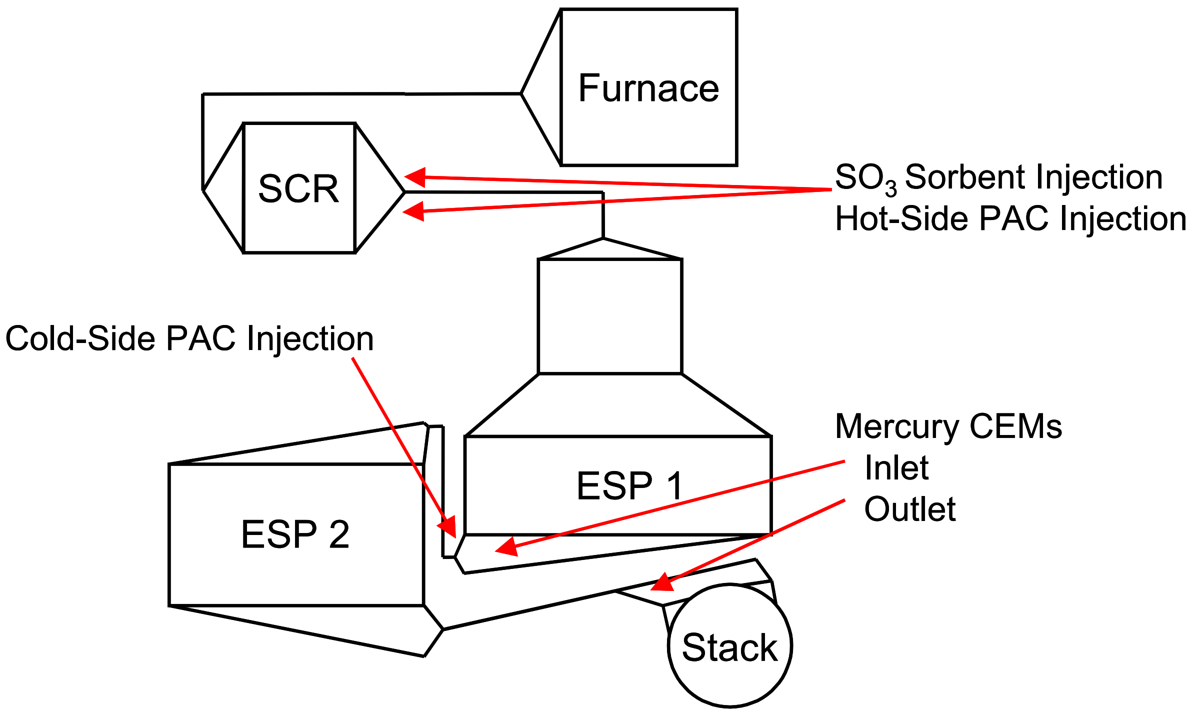

Fig. 1. MK2 configuration and sampling locations.

Table 1. MK2 design parameters.

Boiler	
Type	Cyclone-fired coal furnace
Nameplate (MW)	335
Coal	
Type	Eastern bituminous and Venezuelan
Weight Fraction in Coal Feed	50/50% test blend
Sulfur (wt%, dry)	1.2%
Mercury (mg/kg, dry)	0.06 ppm
Chloride (mg/kg, dry)	1000 ppm
ESP	
Type	Cold-side
ESP Conditioning	None
Specific Collection Area, ESP1/ESP2 (ft^2/1000 acfm)	120/230
ESP Inlet Temperature (°F)	335
NO_x Controls	SCR
SO_2 Controls	Coal blend
Fly Ash Reuse	Cyclone Furnace Reinjection or off-site beneficial reuse (concrete additive, flowable fill)

Test Methods

Continuous mercury measurements were obtained using two Thermo Mercury Freedom System continuous emission monitors (CEMs). Additional mercury measurements were made using the Ontario Hydro (OH) method, the modified Appendix K sorbent trap method (STM), and EPA Method 29 multimetal test procedure.

SO_3 concentrations in the flue gas were measured by E.ON U.S. using modified EPA Method 8A controlled condensate, a manual sampling method. In addition, an in-situ monitoring device developed and supplied by Breen Energy Solutions was used to give real-time measurements of SO_3 concentration. This instrument provides real-time measurements of acid dew point temperatures and, indirectly, SO_3 concentration. This instrument allows for real-time feedback on the effect of sorbent injection on acid dew point. The instrument was installed in October and was effective as a relative indicator of SO_3 levels, as will be discussed shortly.

For the test program, flue gas extraction probes and mercury analyzers were inserted at the ESP2 inlet and outlet, with additional sampling for mercury conducted at various port locations from downstream of the APH to the stack. SO_3 measurements were conducted at the APH outlet, ESP2 inlet, and ESP2 outlet.

All parametric testing occurred with the unit at full load. On each parametric injection test day, one to five injection rates (or combinations of injection rates for dual injection) were tested. Once steady mercury concentrations were achieved, the results were evaluated and new injection parameters established.

The parametric tests results were used to formulate a balance-of-plant test that would allow continuous injection over a period of two weeks. Due to the continuing issues with ash utilization, the continuous injection period was broken into two test periods with two PACs and two SO_3 sorbents selected. From this balance-of-plant continuous injection evaluation period, final parameters were selected for the long-term test, scheduled to range from two to six months.

Sorbent Injection System Design

The primary location for activated carbon injection was in the inter-ESP ducting between ESP1 and ESP2. During parametric testing, activated carbon was also injected in ports located upstream of the APH. The SO_3 injection lances were located at the outlet of the SCR, upstream of the APH. CFD modeling of the PAC injection location was carried out to ensure adequate dispersion of the sorbent. According to the results of the CFD model, residence time for the PAC ranged from two seconds to over four seconds due to the chevron nature of the ESP2 inlet plenum.

RESULTS AND DISCUSSIONS

Baseline Testing

The initial step in the testing program was to establish baseline mercury and SO_3 levels. Baseline native mercury removal across ESP2 was measured to be less than 10% (Table 2). The mercury measurements were performed using Thermo Mercury Freedom CEM units, one at the ESP2 inlet and one at the ESP2 outlet, and confirmed using modified 40CFR Part 75 Appendix K sorbent traps (STM) and Ontario Hydro (OH) measurements. The only deviation from standard performance characteristics of the mercury measurement equipment was the outlet mercury CEM readings. The outlet CEM, despite troubleshooting by ADA-ES, Thermo Fisher Scientific, and a local installation group, continued to read from 0.5 to 1.5 $\mu g/m^3$ above expected readings. While this deviation held steady over the course of many days in between calibration changes, and was within the relative accuracy required of the instrument, it was necessary to apply the correction to prevent nonsensical interpretation of the data; i.e., the inlet reading lower than the outlet during baseline conditions. Therefore, a manual correction was applied to all outlet CEM mercury levels for the first seven months of testing.

Table 2. Baseline mercury levels at inlet and outlet of ESP2.

	Inlet ($\mu g/m^3$)			Outlet ($\mu g/m^3$)		
Date and Time	OH[a]	STM[a]	CEM[a]	OH[a]	STM[a]	CEM Corrected[a, b]
10/5/06 1410-1636	7.4	7.3	8.1	4.5	7.1	8.1
10/6/06 0940-1154	7.3	7.3	8.5	6.9	6.6	8.0
10/7/06 0845-1159	5.7	7.3	7.1	7.4	7.7	8.0
Average	6.8	7.3	7.9	6.3	7.1	8.0
Average Mercury Removal				7.3%	2.7%	~0%

[a]OH measurement is in $\mu g/dsm^3$; STM and CEM measurements are in $\mu g/sm^3$.

[b]CEM corrected for the Outlet CEM measurement indicates a manual correction to the CEM reading.

Co-Benefit Testing

The goal of these tests was to reduce SO_3 concentrations to enable efficient use of activated carbon for mercury control and to reduce the APH cold-end average (CEA) temperature. Co-benefit testing began in October 2006 and field-testing finished in March 2007.

SO_3 concentrations were measured with and without injection with both the Breen in-situ device and manual SO_3 measurements. MgO and trona were injected at different injection rates, without ACI, to determine reductions in SO_3 and the impact on ESP performance. Because of relatively close correlation between manual SO_3 measurements and the Breen instrument (see Table 3), the in-situ monitor was used as the primary indicator of SO_3 concentrations for the rest of co-benefit testing.

Both MgO and trona effectively reduced SO_3 concentrations from the baseline level between 15 and 20 ppm to the 5 to 10 ppm range. Shortly after starting MgO injection, ESP performance began to deteriorate. The ESP performance did not degrade as much or as quickly with trona injection despite the drop in SO_3 concentrations and the subsequent change in ash resistivity (an assumption that was tracked by measuring the pH of the ash).

Because of the relatively large particle size of both MgO and trona, tests were also conducted using a pin mixer to mill the products to smaller particle sizes.

Table 3. Comparative SO_3 levels during baseline and SO_3 mitigation testing.

Test Condition	SO_3 Measurements (ppm)	
	Breen	Manual Measurements
Baseline	10–20	15–20
MgO Injection	5–12	No measurement
Trona Injection	7–10	7–10
Milled trona injection	0–10	No measurement

Comparison of MgO and Trona

Magnesium oxide (MgO) is a dry sorbent with a relatively low density—25 lb/ft^3. As such, it is easily handled by standard bulk conveying equipment. The MgO is specified to be delivered with a particle size of under 5 microns. It appears that the material agglomerates in transit. The effect of MgO injection on measured SO_3 concentrations (as measured by the Breen in-situ monitor) appeared to be similar to the effect of trona injection. MgO does not have any impacts on the ability of the plant either to utilize/dispose the ash or to re-inject the MgO–fly ash mixture into the cyclone boiler combustion process for by-product sales.

Trona (sodium sesquicarbonate) is a dry sorbent with a higher density than MgO—75 lb/ft^3. This density is more difficult for standard bulk conveying equipment, which requires either a system specifically designed for higher density material or 24-hour coverage of the injection system. As delivered, trona has a particle size averaging 30 microns. With pin milling, the particle size can be decreased to 15 microns. Other milling options can reduce the particle size to 5 microns. Trona injection for SO_3 control limits the options for ash by-product utilization, because it increases the sodium content of the fly ash.

Parametric Testing

Parametric test conditions are summarized in Table 4. The PAC sorbents selected for the parametric tests were NORIT's DARCO® Hg and Hg-LH and Calgon's FLUEPAC™-MC PLUS. The DARCO® Hg-LH and FLUEPAC™-MC PLUS are brominated PAC while DARCO® Hg is a standard PAC. In addition, NORIT provided a developmental sorbent, DARCO® E-26, which was designed to overcome some of the impact of high SO_3 concentration and was based on the DARCO® Hg-LH brominated PAC. The number of tests and parameters evaluated evolved as results were obtained and new information learned from other test sites. The tests were divided into four conditions (I–IV):

I. Carbon injection only, injection location between the two ESPs.

II. Dual injection with trona injection for SO_3 control upstream of the APH and carbon injection between the two ESPs.

III. Carbon injection only, upstream of the APH (recent tests at other sites showed some of the impacts from SO_3 could be mitigated when the injection location was moved to upstream of the APH).

IV. Dual injection with MgO injection for SO_3 control upstream of the APH and carbon injection between the two ESPs.

Table 4. Summary of parametric test conditions.

Test ID	Dates	Carbon ID	SO_3 Sorbent	Cold-End Ave. Temp	ACI Location
I – 1	Nov. 2006	DARCO® Hg-LH	None	Normal	Between ESPs
I – 2	Dec. 2006	DARCO® Hg-LH E-26	None	Normal	Between ESPs
I – 3	Jan. 2007	DARCO® Hg-LH E-26 (Batch 2)	None	(-) 30ºF	Between ESPs
II – 1	Jan. 2007	DARCO® Hg	Trona	(-) 30ºF	Between ESPs
II – 2	Jan. 2007	DARCO® Hg-LH	Trona	(-) 30ºF	Between ESPs
III – 1	Jan. 2007	DARCO® Hg-LH	None	Normal	Upstream APH
IV – 1	Feb. 2007	DARCO® Hg-LH	MgO	Normal	Between ESPs
IV – 2	Feb. 2007	Calgon FLUEPAC™-MC PLUS	MgO	Normal	Between ESPs
IV – 1	Mar. 2007	DARCO® Hg	MgO (milled)	(-) 30ºF	Between ESPs
IV – 2	Mar. 2007	DARCO® Hg	MgO	(-) 30ºF	Between ESPs

In addition to the four primary parametric conditions, other variables included sorbent type, injection rate of carbon, injection rates of the SO_3 sorbents MgO and trona, and changing cold-end average (CEA) temperature. Two production versions of DARCO® Hg-LH E-26, a NORIT carbon developed specifically for high SO_3 flue gas, were tested. Standard brominated carbons from NORIT Americas and Calgon Carbon were also evaluated.

Figures 2 and 3 present examples of mercury removal rates and plant conditions during parametric tests. These graphs include inlet and outlet mercury (as measured by the CEMs), mercury removal and carbon injection concentration, and CEA temperature.

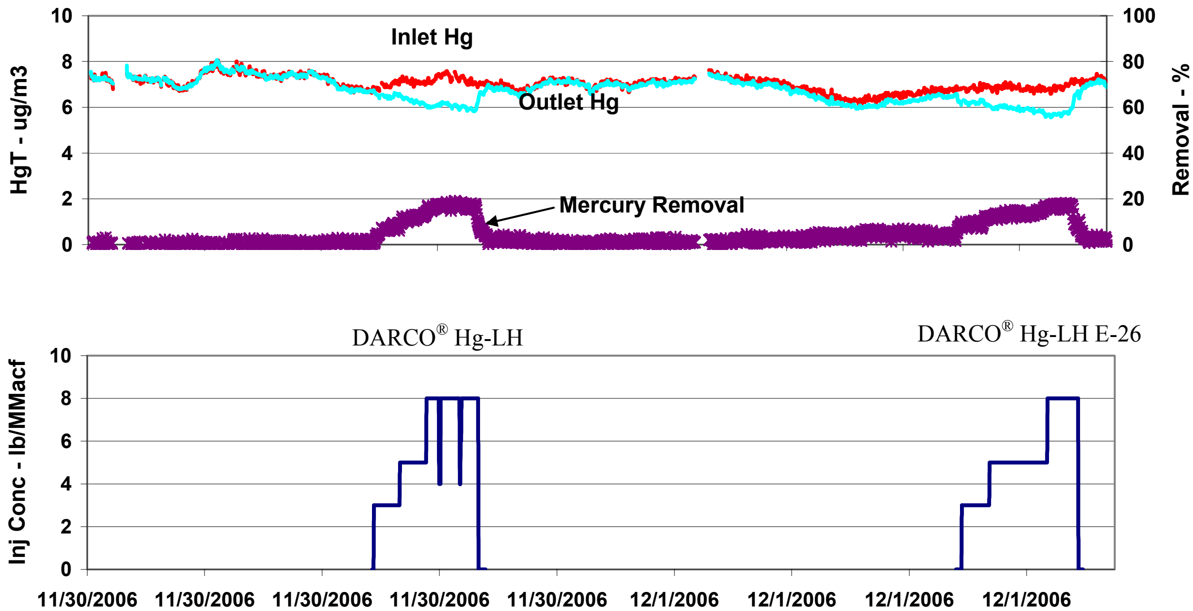

Fig. 2. Trend data, parametric testing December 2006.

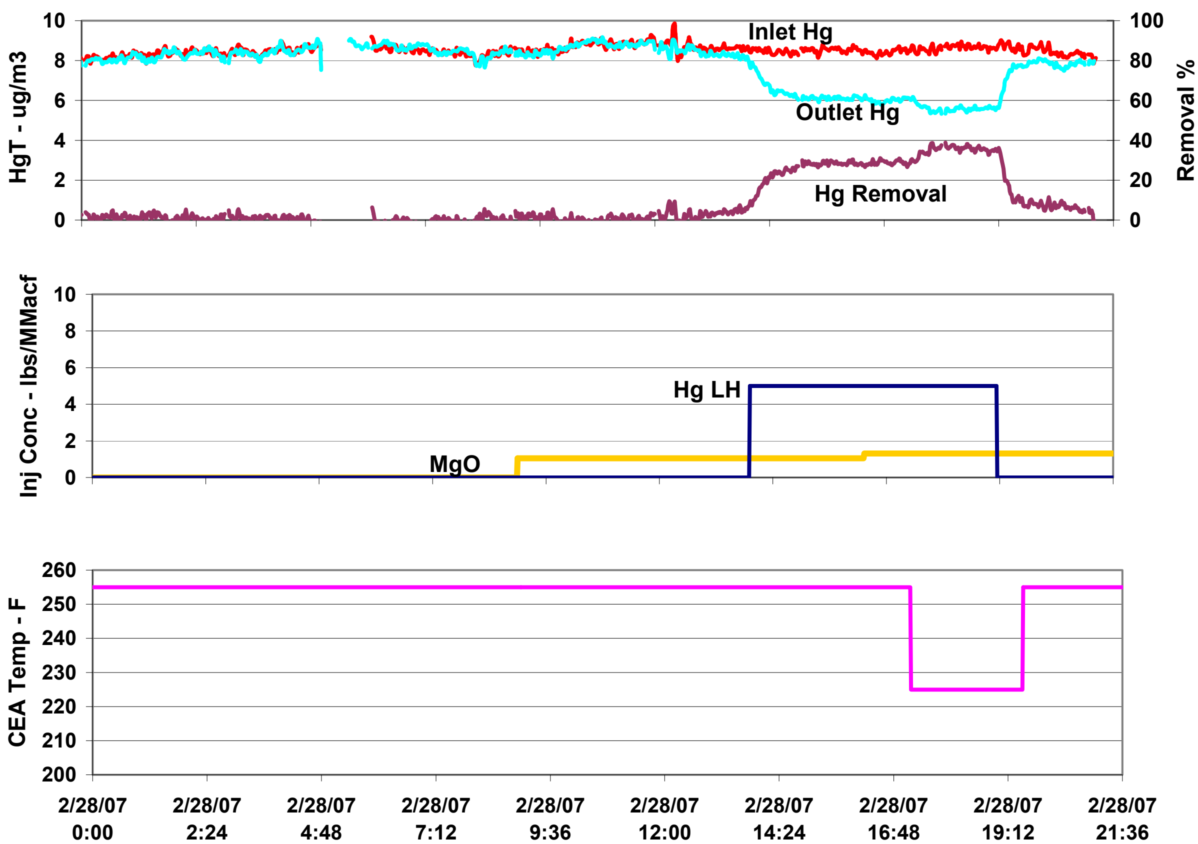

Fig. 3. Trend data, parametric testing February 28, 2007.

The performance of the PAC sorbents was affected by both the SO_3 concentration and the outlet temperature of the APH (affected by changing the set point for CEA). Without modification of either of these two parameters, mercury removal was limited to less than 22% with any of the activated carbons at injection concentrations up to 8 lbs/MMacf. When CEA temperature was lowered without the addition of an SO_3 sorbent, mercury removal with E-26 increased to about 31%.

Significant improvement in mercury removal was achieved when the SO_3 concentrations were lowered by sorbent injection. As discussed earlier, two SO_3 sorbents were tested during dual injection trials: trona and MgO. MgO allows the site several options to utilize their fly ash. Trona imposes more limitations on the plant with regard to fly ash utilization, because of trona's sodium content.

Testing showed that of the two SO_3 mitigation sorbents, dual injection with trona appeared to be more effective at increasing the effectiveness of the activated carbon for mercury removal. When injecting DARCO® Hg-LH at 5 lbs/MMacf, mercury removal with trona was 15% higher than when injecting MgO with a similar injection rate: 30% versus 45% at normal temperatures and 40% versus 55% with lower CEA temperatures. Trona might have less interference from SO_2 than the MgO and therefore might be more effective at reducing SO_3 at a lower molar ratio (alkali to SO_3) than MgO. The use of trona thus results in lower SO_3 in the flue gas, which improves the ability of activated carbon to adsorb mercury. There are no empirical data to support this supposition as of yet because manual SO_3 concentration levels were not measured with MgO injection, but only during baseline testing and when trona was injected.

The highest mercury removal of 65% was achieved with trona injection coupled with the injection of the standard carbon, DARCO® Hg, at about 8 lbs/MMacf, and lowered CEA temperatures. Although subsequent data discussed later in this paper showed an improvement in performance with a brominated carbon, these data did not.

Parametric testing also included a detailed look at balance-of-plant issues concerning ESP performance (see Figures 4 and 5) and opacity with the dual injection concept. ESP parameters were not logged automatically during these tests, so all ESP data were taken manually several times a day, with more frequent visual checks if parameters appeared to be changing.

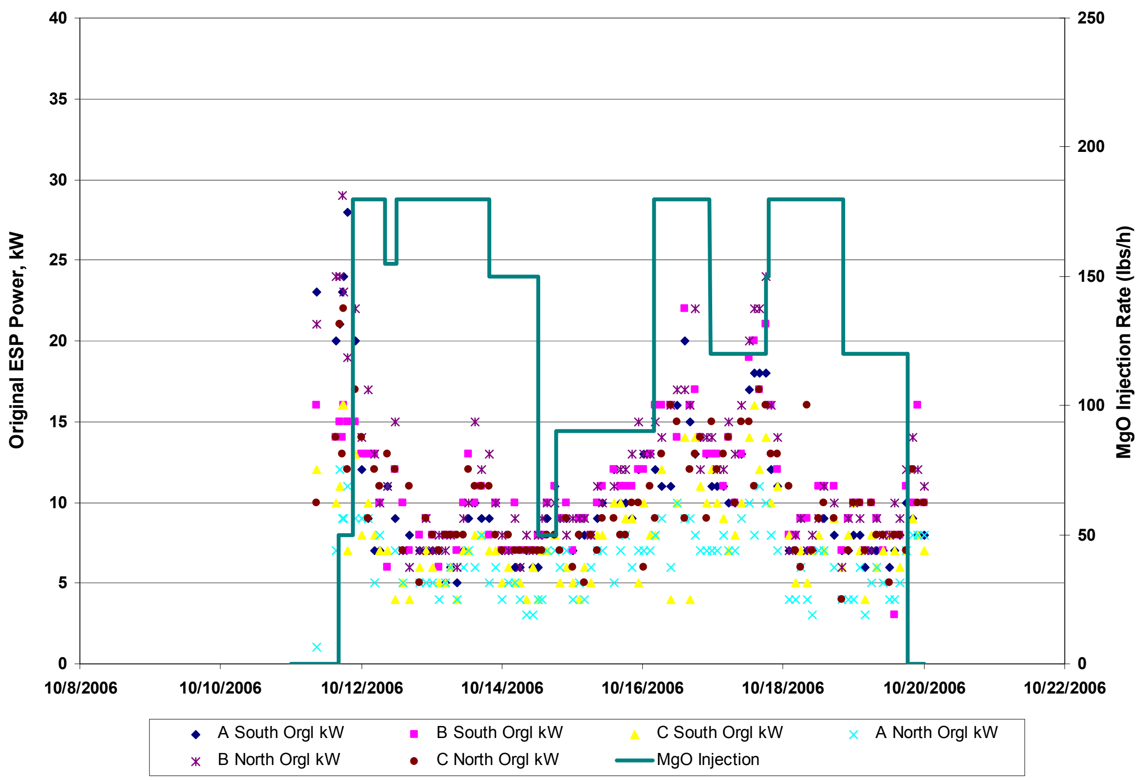

Fig. 4. Original (ESP1) ESP power levels during MgO injection.

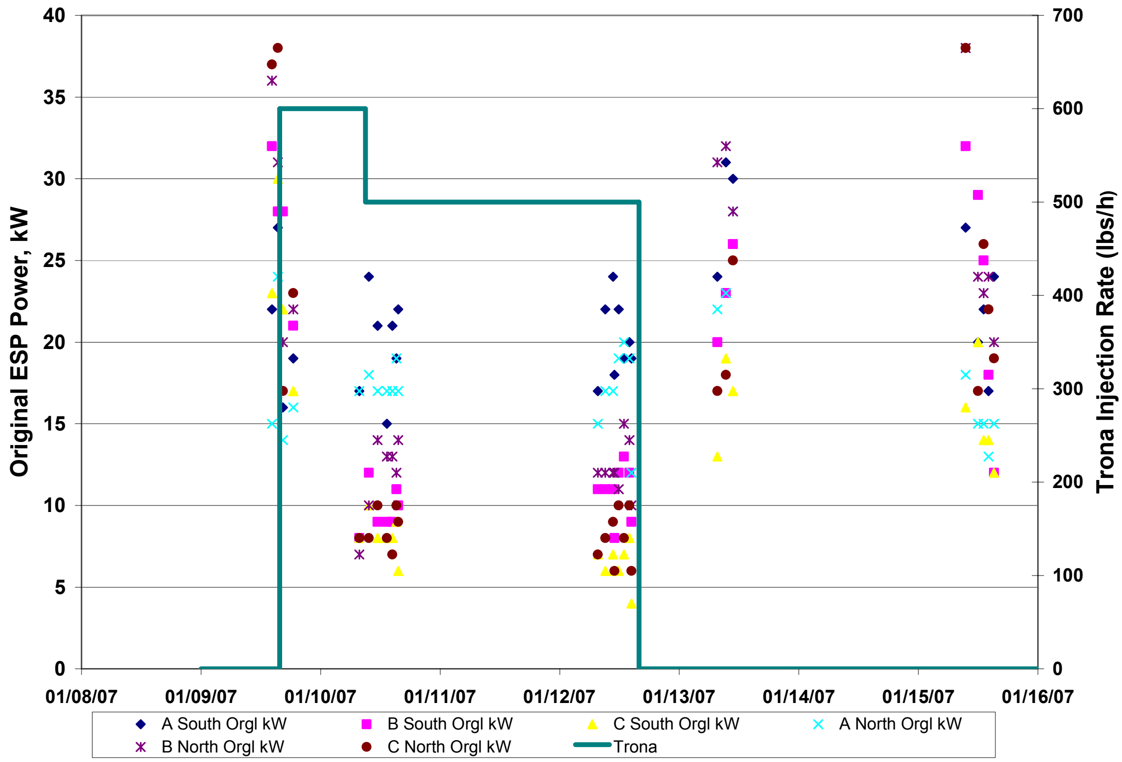

Fig. 5. Original (ESP1) ESP power levels during trona injection.

While both MgO and trona have an impact on ESP performance, the trona injection generally allows a higher power level to be maintained in the original ESP during injection periods. Opacity also increased more during MgO injection versus trona injection. Opacity increased above baseline by 1–2% with trona injection, while MgO injection increased opacity by 2–4%. When MgO was injected, the plant re-injected ash from ESP1 back into the boiler, which caused about a 1–2% increase in opacity. The increase in opacity reported above for MgO is in addition to the increase in opacity resulting from ash re-injection to the boiler.

Balance-of-Plant Continuous Injection Testing

Prior to a plant outage scheduled for mid-April 2007, the test team decided that additional data was needed relative to the potential plant impacts from long-term testing with dual injection. In these tests it was important to run the equipment continuously to determine if any potential balance-of-plant issues could be identified prior to the outage, providing an opportunity to possibly address any problems during the outage.

The balance-of-plant tests were conducted using the two SO_3 mitigation sorbents tested during parametric testing. Parametric testing had demonstrated that trona injection was superior to MgO injection in combination with PAC injection at enhancing mercury removal from the flue gas. Trona was also less expensive to treat an equivalent amount of flue gas for SO_3 mitigation. However, due to its sodium content, trona was significantly more difficult to find a beneficial end use for when injected into the flue gas stream, meaning that the fly ash would likely be consigned to a landfill. At the time of the test, there was no viable path to dispose of the trona–fly ash mixture, although PSNH continued to resolve this issue. For this reason, testing continued with both MgO and trona to ascertain the cost and balance-of-plant issues to attain the DOE goals for mercury removal with both SO_3 sorbents.

Brominated and non-brominated sorbents, DARCO® Hg-LH and DARCO® Hg, were tested during this phase as well. The cost of the SO_3 mitigation effort was beyond the initial budget estimates and paths were being evaluated to reduce the overall cost of the long-term tests. If reasonable results could be attained with the non-brominated sorbent, the cost benefit of using the non-brominated sorbent could be considered for long-term use at the site.

Continuous injection commenced March 30, 2007, with MgO and DARCO® Hg and DARCO® Hg-LH. A pin milling system was leased and brought on site to evaluate the potential benefits of increasing the surface area of the MgO to increase its effectiveness on SO_3 removal. The pin milling system was also evaluated with trona and DARCO® Hg-LH.

The initial test run was made with milled MgO (injected upstream of the APH) and DARCO® Hg (injected between the two ESPs). The resulting mercury removal remained in line with previous parametric testing and opacity increased. These results suggested that milling of the MgO did not appear to decrease the SO_3 content of the flue gas relative to the unmilled MgO. Based on the significant increase in opacity (with opacity increasing on one occasion to over 30% for the six-minute average), it was decided after two days to continue MgO injection without milling. MgO injection continued with both DARCO® Hg and DARCO® Hg-LH for seven days. The results were in line with previous parametric results, less than 40% mercury removal, as can be seen in Figure 6. Balance-of-plant issues beyond that discovered during parametric testing were limited to the increased opacity when milling MgO.

Testing was then initiated using milled trona and DARCO® Hg-LH. The milled trona did not result in the opacity increases observed with the milled MgO. This was an expected result as previous parametric tests had always indicated that MgO increased opacity by 2–4% over that experienced during trona injection. The mercury removal performance when using milled trona and brominated carbon was above the previous parametric test results (Figure 6). Inlet and outlet STM results and the outlet CEM indicated mercury removal across the ESP of around 90%. These high removal rates are preliminary; the result of a short continuous injection period during a single multi-hour event (approximately 6 hours in duration) that has not been verified through repetition of the test conditions, and needs to be substantiated during long-term testing. This removal occurred when injecting at 500 lb/hr of trona and 400 lb/hr (6 lb/MMacf) of DARCO® Hg-LH. The trona was injected upstream of the APH, milled to less than 15 microns, and the unmilled DARCO® Hg-LH was injected in between ESP1 and ESP2. APH CEA was reduced from 255ºF to 225ºF in accordance with previous parametric testing.

The increase in mercury removal through the use of the milling system for trona may not be directly attributable to trona. The conveying air used to carry the milled trona was different from that used for the unmilled trona and MgO, both milled and unmilled. There is a possibility that the increased airflow provided better distribution for the milled trona and therefore was the cause of the increased removal. This concept will be tested during Long-Term testing.

The milling system selected by O'Brien & Gere, the trona injection contractor, was a pin milling system. The pin milling system is a mechanical milling process that mills the trona sorbent down to below 15 microns (from 35 microns). This mechanical milling process transferred heat from the mill to the conveying system. This resulted in the mill coming off-line every 12 hours to be cleaned from the hardened deposits of trona. O'Brien & Gere have since developed an alternative means of maintaining the pin mill online, and there are other options available for milling that will minimize heat transfer to the trona.

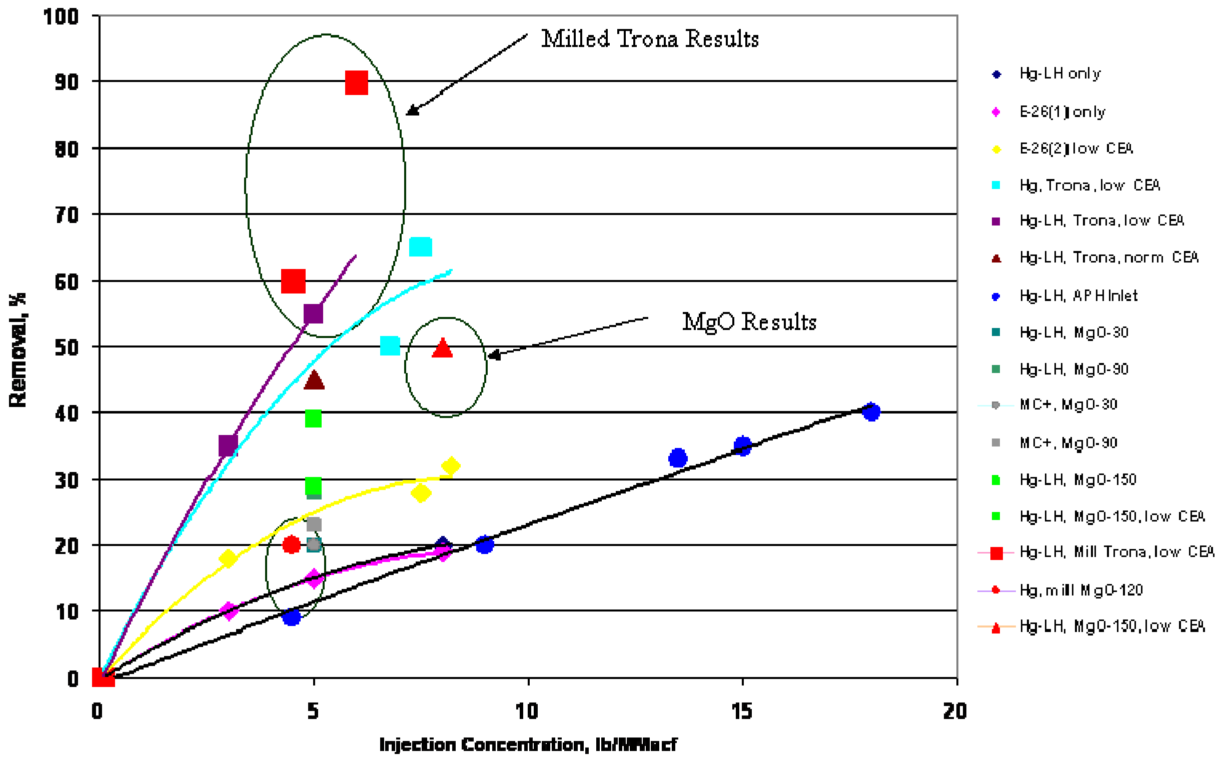

Fig. 6. Balance-of-plant and parametric testing results.

CONCLUSIONS

The ACI test program conducted at MK2 demonstrated that high levels of mercury removal could be achieved with carbon sorbents during short-term testing. The caveat is that high mercury removal can only be achieved by lowering flue gas SO_3 levels and flue gas temperatures at the air preheater outlet. The costs associated with a dual injection system, or an on-site milling-mixing process for the two sorbents, may reduce the cost advantages of the ACI system over other co-benefit systems. There is some potential that development of a novel sorbent that is tolerant of an SO_3 flue gas environment will reduce the capital costs, but the probable increased cost of that novel sorbent over standard PAC sorbents may reduce its viability. The other unknown, which needs to be further investigated, is the long-term impact on opacity from the increased particulate loading due to the injection of both the SO_3 sorbent and the PAC sorbent into the flue gas stream.